Product handbook for the Airborne Precipitation Radar Second Generation (APR-2): SEAC^{4}RS 2.3 (R23)

Experiment: SEAC^{4}RS, Aug/Sep 2013, Houston TX, DC-8, CONUS & Gulf of Mexico

Filename: standard: APR2.yymmdd.hhmmss.2x.HDF,

seac4rs repository: SEAC^{4}RS-APR2_DC8_yyyymmddhhmmss.R2x.h4

Note: yymmdd_hhmmss indicates the UTC start time of the data.

Format: 2.X – Standard L1 product. Geolocated and calibrated radar reflectivity at Ku and Ka band, mean Doppler velocity and Linear Depolarization Ratio at Ku band, surface Normalized Radar Cross Section at Ku and Ka band, precalculated geodetic coordinates of every sample point

Release: X.3 (Preliminary data release to the SEAC^{4}RS repository, April 2014)

Change log:
X.0 – In field data, configuration and calibration changes applied during the experiment.
X.1 – End of campaign reprocessing, full reprocessing with configuration control (Oct 2013). For internal QC only.
X.2 – First preliminary reprocessing, released with caveats to requesting users. Significant calibration adjustments not applied to this version. Absolute calibration uncertainty 1-sigma estimate 3 dB.
X.3 – First Science Team release of preliminary processing. Absolute calibration uncertainty 1-sigma estimated at 0.7 dB for Ku-band, 1.2 dB for Ka-band.

Data Format (version 2.x)

APR-2 data are saved in HDF format.
The fileheader is stored as Vdata; the remaining items are Scientific Data Sets (SDSs).

Name	**format**	**size**	Units	**Notes**
fileheader	int32	38		See description in Table 2
scantime	int32	nscan x nray	s	Beginning of scan in seconds since 1 January 1970 Note: to obtain the time of each ray, parameters 1 and 7 from the fileheader are necessary
lat	float	nscan x nray	deg	From aircraft or MMS navigation files
lon	float	nscan x nray	deg	From aircraft or MMS navigation files
roll	float	nscan x nray	deg	From aircraft or MMS navigation files
pitch	float	nscan x nray	deg	From aircraft or MMS navigation files
drift	float	nscan x nray	deg	From aircraft or MMS navigation files
alt_nav	float	nscan x nray	m	From aircraft or MMS navigation files (recommended)
alt_radar	float	nscan x nray	m	From APR-2 surface echo (alternate)
look_vector	double	nscan x nray x 3		From navigation files (recommended)
look_vector_radar	double	nscan x nray x 3		From APR-2 surface echo (alternate)
range0	float	nscan x nray	Km	Distance of the first radar range bin from a/c
isurf	int32	nscan x nray		Index of radar range bin intersecting surface (starting from 0).
sequence	int32	nscan x nray		Ray number within the file
v_surfdc8	float	nscan x nray	m/s	Apparent surface Doppler velocity as estimated from P-3 navigation
v_surf	float	nscan x nray	m/s	APR-2 measured surface Doppler velocity
beamnum	float	nscan x nray		Ray number within a scan
surface_index	float	nscan x nray		Preliminary surface classification index
sigma_zero	float	nscan x nray x 2	dB	Surface NRCS (Ku and Ka band)
zhh14	int16	nscan x nray x nbin	dBZ	Radar Reflectivity at Ku band (scaled dBZ)
zhh35	int16	nscan x nray x nbin	dBZ	Radar Reflectivity at Ka band (scaled dBZ) nadir port
ldr14	int16	nscan x nray x nbin	dB	Linear Depolarization Ratio (scaled dB)
vel14	int16	nscan x nray x nbin	m/s	Doppler Velocity at Ku band (scaled m/s)
zen35	int16	nscan x nray x nbin	dBZ	Radar Reflectivity at Ka band (scaled dBZ) zenith port
lat3D	int16	nscan x nray x nbin	deg	Latitude of each resolution bin
lon3D	int16	nscan x nray x nbin	deg	Longitude of each resolution bin
alt3D	int16	nscan x nray x nbin	m	Altitude of each resolution bin
lat3D_scale	double	1		
lon3D_scale	double	1		
alt3D_scale	double	1		
lat3D_offset	double	1	deg	
lon3D_offset	double	1	deg	
alt3D_offset	double	1	m	

nscan is the number of scans in a file, nray is the number of rays (aka: beams, looks) within a scan, and nbin is the number of range bins within a ray.

Missing data are replaced by –9999.

Altitude and Look Vector (i.e., the 3 components of the antenna relative to a global coordinate system with *x* being the aircraft ground track and *z* being vertical) are provided in two estimates: alt_nav and look_vector are calculated relying on the aircraft navigation information, instead alt_radar and look_vector_radar are calculated relying on the observed surface return in APR-2 data. The latter pair is reliable only when flying over ocean, and in this case it provides a more accurate geolocation than the navigation-based pair. See notes in the next section for specific recommendations with this data release.

The predicted (v_surf_nav) and observed (v_surf) surface Doppler velocities are provided: v_surf was corrected for occasional aliasing and, in turn, it was used to correct the Doppler measurements of precipitation for the bias introduced by the aircraft motion. This correction can be undone by the user by adding the value of v_surf from vel14 at all the range bins of every ray. The alternate correction using the Doppler estimated from navigation data can be then obtained by subtracting the value of v_surf_nav from vel14 at all the range bins of every ray. This alternate correction may be of interest for the minority of data collected over land where the v_surf estimate is more prone to errors, or for data collected during sharp maneuvers by the DC-8.

The surface index is estimated by analyzing APR-2 surface return (roughness, angle dependence of the surface normalized radar cross section, apparent surface inclination and LDR at nadir). It assumes one of 6 values (this classification is preliminary, see next section for known issues):

- 0 = Rough land
- 1 = Ocean (level flight)
- 2 = Ocean (roll maneuver)
- 3 = Flat land (level flight)
- 4 = Flat land (rolling maneuver)
- 5 = Antenna not scanning (unknown surface)

The file header contains information about the APR-2 data. These are parameters that are constant over the entire file. Table 4 shows the file header.

File header

	Name	Src	Unit	Default	Description
1	PRF	Raw	Hz	5000	Pulse repetition frequency in Hz
2	Pulse Length	Raw	mus	3-20	Radar pulse length in 1 us units
3	Antenna Left	Raw	deg	-25 or 0	Antenna scan left-limit in deg.
4	Antenna Right	Raw	deg	+25 or 0	Antenna scan right-limit in deg.
5	Scan Duration	Raw	ms	1200	Scan time for antenna in second * 100
6	Return Duration	Raw	ms	600	Antenna retrace time in second * 100
7	Ncycle	Raw		250	Number of pulse averaged by Wildstar board
8	AZ Average	Raw		1	Number of blocks averaged in a beam or ray
9	Range average	Raw		1	Number of 30m range cells averaged in a bin
10	Scan average	Raw		1	Number of scans averaged
11	Number of Bins	Raw		600	Number of range bins in the ray
12	Number of Beams	Raw		24	Number of rays in each scan
13	Range Bin Size	2HDF	m	30	The vertical resolution of range bin
14	Z scale factor	Raw		100	Factor multiplying reflectivity
15	V scale factor	Raw		100	Factor multiplying Doppler
16	Not used	write			Always the number 1
17	# of scans	L1A			Number of scans
18	CalVersion	write			obsolete
19	Radar Mode	L1A			spare 1: mode (71 = dump, 87 = operate)
20	Rx Atten	L1A			Internal Cal parameter
21	Tx Atten	L1A			Internal Cal parameter
22	DR	Env	m		A priori range sampling (redundant)
23	Zenith Port	Env			0 ➔ Ka (2) = CxPol; 1 ➔ Ka(2) = Ka Zenith
24	Fixed Ka Pt	L1A			
25	Not used				
26	Not used				
27	Not used				
28	Not used				
29	Not used				
30	Not used				
31	Not used				
…	Not used				
38	Not used				

List of flights and datasets: SEAC^{4}RS

#	Date	Observation	Proces. level	GB (raw)	Notes
1	2013, Aug 2	Test Science Flight in California/Pacific Ocean	5.0	2.8	Not available in release 3
2	2013, Aug 5	Test flight	5.0	2.2	Not available in release 3
3	2013, Aug 6	Light snowfall	5.0	4.3	Not available in release 3
4	2013, Aug 8	Transit DAOF-EFL	5.3	4.1	Clear Air Ocean, Arid Land and Urban, ligt precip and virga over TX
5	2013, Aug 12	Sci Flt #1: Birmingham Wall and Dry Run of Conv. Module w LearJet	5.3	3.9	Ocean, small cell precip, old convection
6	2013, Aug 14	SEUS	5.3	3.5	Cirrus shield and stratiform rain
7	2013, Aug 16	NAM	5.3	2.8	Strong shallow prefrontal convection in WTX, Clear Air Arid Land
8	2013, Aug 19	Wyo Smoke	5.3	1.9	Clear Air Land
9	2013, Aug 21	Radiation cut PBL, Small conv Module	5.3	5.7	Isolated convection and anvil
10	2013, Aug 23	Convective Module with LearJet	5.3	7.0	Isolated convection and anvil
11	2013, Aug 26	Rim Fire & Idaho	5.3	4.1	NAM precipitation in AZ/NV
12	2013, Aug 27	Return from Spokane, Smoke	5.3	6.4	Clear Air Land, Cirrus, Pollen (?)
13	2013, Aug 30	SEUS, Ozarks	5.3	4.2	Small isolated convection & stratiform
14	2013, Sep 2	Land convective flight	5.3	8.3	Lots of convection over land
15	2013, Sep 4	Gulf convective flight	5.3	5.8	Lots of convection over the Gulf
16	2013, Sep 6	Chem and NAM, Ozarks	5.3	2.9	Clear Air Land
17	2013, Sep 9	Agr Burn, CALIPSO	5.3	0.8	Clear Air Land
18	2013, Sep 11	SEUS, Cu	5.3	4.6	Anvil over Land
19	2013, Sep 13	TS Ingrid outskirts	5.3	6.3	Convection & stratiform over gulf
20	2013, Sep 16	Ship channel, ATL plume, Agr. burning	5.3	4.5	Isolated small convection & cirrus, mostly from zenith port
21	2013, Sep 18	Gulf convection with Lear, and Fracking fields in E TX	5.3	3.5	Convective over land and ocean
22	2013, Sep 21	Wall ahead of a large front, Ozarks	5.3	8.1	Stratiform Wall
23	2013, Sep 23	Transit EFL-DAOF, ship channel, agr. Burning, Brawley plant, Salton Sea	5.3	4.0	Clear Air Land

Total 101.7 GB of raw data for ~83 hrs of radar operation during the ~180 hrs of DC-8 flight. No unintended interruptions of data acquisition occurred during SEAC4RS.

HDF 4 Release 2.3 requires approximately 9.6 GB compressed.

Known Problems, issues and other notes

This section lists all known problems with the APR-2 SEAC^{4}RS v2.0 data.
Some of these problems are caused by problems in the raw data, while others are processing problems.

- External calibration was used for all products. Reflectivity measurements should be considered reliable within ±3 sigma as reported in the cange log for this release.

- Many files (usually all the ones acquired at low altitude) are acquired in DUMP MODE (indicated in the FILE HEADER 19th variable, see Table 2): all measurements from the nadir channels in this mode are to be considered as NOT CALIBRATED. Only the Zenith port measurements are calibrated when in DUMP MODE.
- During SEAC4RS multiple configurations were adopted to adapt to the extremely variable nature of the targets and DC-8 flight patterns. It is important to understand that the radar sensitivity was not constant (mainly dependent on the pulse length). Users not familiar with the weather radar equation and APR-2 data should contact the APR-2 team to support data interpretation.
- The new APR-2 radome, Ka-band TWTA, and improved noise subtraction allowed to lower the Ka-band minimum detectable reflectivity to about -15dBZ at 10 km distance (-21 @ 5 km distance). Thresholding was kept just above the noise floor max to provide clean data and images, however, in some scenarios the warm background brought the noise floor above the threshold. In this release we chose to keep those occurrences visible as they are excellent markers of warm rain processes or land surface background. In the browse images they can be seen 'wakes' above the actual reflectivity; usually grey above ~5 km altitude, and purple below it, following the $10*\log10(r^2)$ shape of the noise floor.
- In the short range (that is the first 5 bins after the blanked transmit window) the reported value of reflectivity is underestimated. This region should be used only for detection purposes, and not quantitative estimation.
- radar reflectivity factors are as measured – no correction for path attenuation is included in these products.
- The radar altitude and look_vector are occasionally affected by aircraft motion at a sub-scan timescale.
- This data version was produced using the 1Hz from DC-8 (iwg1). It is recommended to use look_vector and alt_nav for all processing as they are accurate in general.
- In some files the Nbin field in the fileheader is set to 1. Ignore this field. Nbin = 600 for all products from SEAC4RS.
- No data are available from the 24th ray of each scan (beamnum = 1). This ray was used for noise measurements (no pulse transmitted). The 24th ray was included in this dataset solely for compatibility with APR-2 datasets from previous experiments.
- LDR estimates are included in this release for the Ku-band channel. Users are cautioned in interpreting very low values of LDR (e.g., less than -20 dB) which are characterized by larger overall uncertainty.
- Antenna and range sidelobes show up as artifacts in data in some cases (i.e., thin feature at constant range appearing at large scan angles a few hundred m above the surface).
- Occasionally, high lateral winds caused the Doppler measurements to be aliased. Doppler measurements should be corrected accounting for a maximum unambiguous

velocity of ±27.5 m/s. Also, correction for aircraft motion is less reliable when the aircraft was maneuvering or was affected by turbulence. Correction for aircraft motion over land is not reliable.

- The surface_index is estimated on a scan-by-scan basis. The most frequent misclassification is ocean being classified as flat land.
- The isurf index is occasionally misdetected because of extreme attenuation in the rain profile.
- Occasional data files are acquired in no-scan mode. They are indicated by the value 5 in surface index product.
- Occasional high surface reflectivity caused overflows in the Ku-band copolar channels causing data quality deterioration. Known occurrences are listed in table below.
- Occasional intermittent changes in the overall calibration are not properly accounted for. Known occurrences are listed in table below.
- Occasionally processing artifacts show up in the browse images but are not actually present in the data.

Known anomalous data periods, approximate times:

Date	Start UTC	Duration [min]	Band
2013/08/08	18:35	<1	Ka cal anomaly

Geolocation

Simplified logic steps to obtain the coordinates of every point in the 3-D dataset.

- **boldface indicates 3-D vectors**
- blue indicates parameters included in the HDF file

For each ray:

1. Aircraft position in geodetic coordinates: $\boldsymbol{G_a}$ = *(lat, lon, alt_nav);*
2. Aircraft position in GPS coordinates: $\boldsymbol{P_a}$ = *standard conversion of* $\boldsymbol{G_a}$
3. Aircraft instantaneous motion: $\boldsymbol{V_a} = \partial \boldsymbol{P_a} / \partial t$
4. Aircraft instantaneous direction: $\boldsymbol{D_a} = \boldsymbol{V_a} / | \boldsymbol{V_a} |$
5. Ray pointing direction in aircraft motion reference: ***look_vector***
6. Ray pointing direction in GPS reference: $\boldsymbol{D_{ray}}$ = *rotate* ***look_vector*** *on* ***Da*** *frame*
   - Look vector has x-axis along direction of motion, y axis to the left and z axis at zenith
7. Range of i-th range bin [m]: $r = range0 * 1000 + DR * i_{bin}$
8. Position of the i-th range bin: $\boldsymbol{p_i} = \boldsymbol{P_a} + r * \boldsymbol{D_{ray}}$
9. Position of the i-th range bin in geodetic coordinates: $\boldsymbol{g_i}$ = *standard conversion of* $\boldsymbol{p_i}$

Format 2.x

For APR-2 data in format 2.0 one can use the following:

The value of coordinate *xxx* (*xxx = lat, lon or alt*) can be obtained as:
xxx = xxx3D / xxx3D_scale + xxx3D_offset

The precision is on 1/10000 degree for latitude and longitude, 1 m for altitude. Geolocation in this format is obtained using a local sphere approximation for Earth. Users in need of more accurate geolocation should follow the procedure described above with their own choices for the coordinate conversion process.

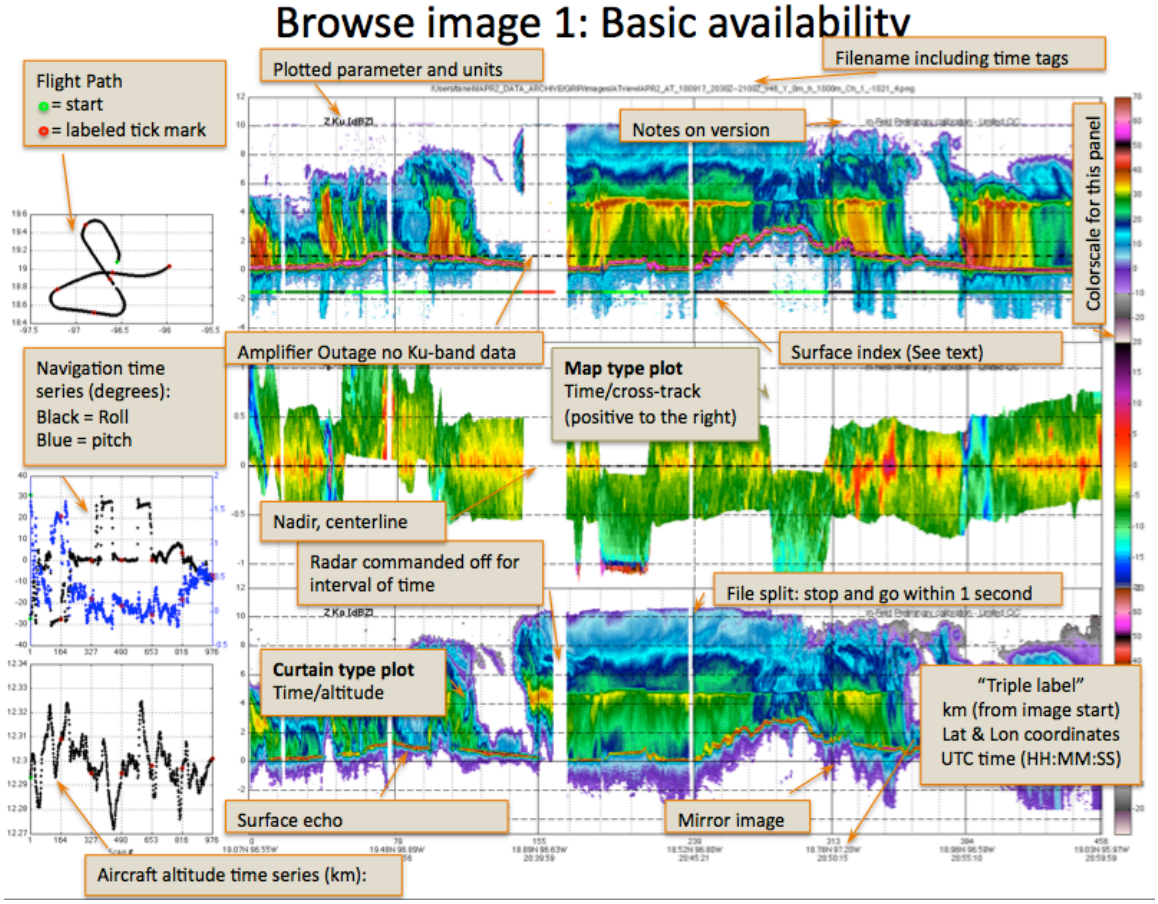
Browse images

Standard browse images are generated in 30 min intervals (less if at the beginning or end of a flight) starting on the hour and half-hour. 4 browse image files are generated for each interval. Each browse image includes navigation and a set of curtain plots and map plots:

Curtain plots: these are vertical sections below the aircraft. The closest beam to the nadir direction is used at every point. The section departs from vertical when the aircraft rolls more than the APR-2 scan angle. In the standard browse images the section is always at nadir (0 cross track displacement). Whenever a non-zero cross-track displacement is chosen (for custom made images) the cross-track displacement is shown in the first map plot by a dot-dash line.

Map plots: these are horizontal sections across the APR-2 swath. They include maps of surface properties (e.g., sigma_zero, v_surf etc.), or sections of volumetric properties (e.g., radar reflectivity at Ku or Ka band, mean Doppler velocity, etc.) at a predetermined altitude. The selected altitude is shown in the first curtain plot as a dot-dash thick line.

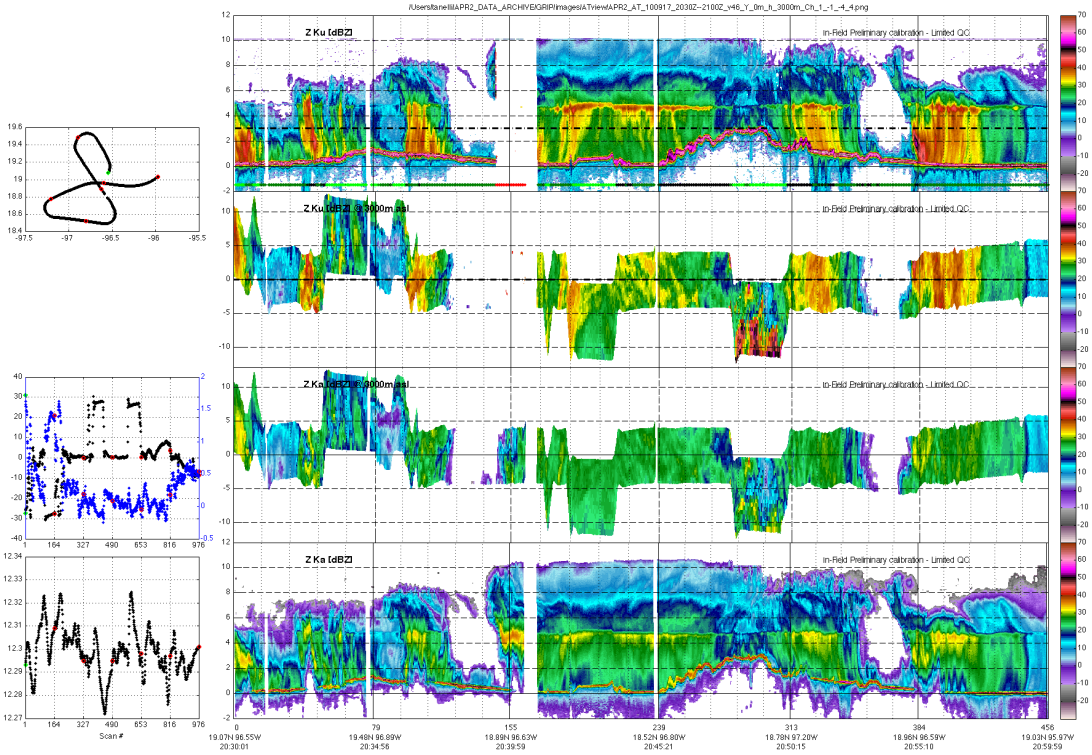
Browse image 1: Basic data availability



Top to bottom:

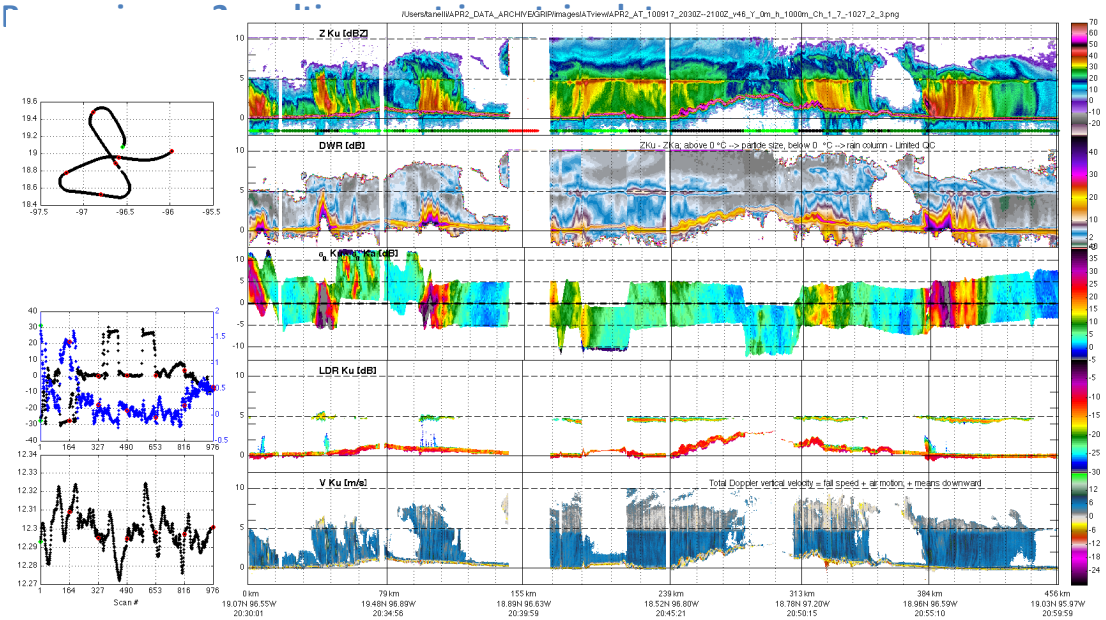
1) Vertical curtain of measured Ku-band reflectivity [dBZ].
2) Swath of Normalized Radar Cross Section [dB].
3) Vertical curtain of measured Ka-band reflectivity [dBZ]. For datasets where the Zenith port was used (e.g., SEAC4RS) this panel will also show the DC-8 flight altitude (in red dash) and Ka-band data above the plane.

Browse image 2: Vertical and horizontal sections of reflectivity at both frequencies



Top to bottom:

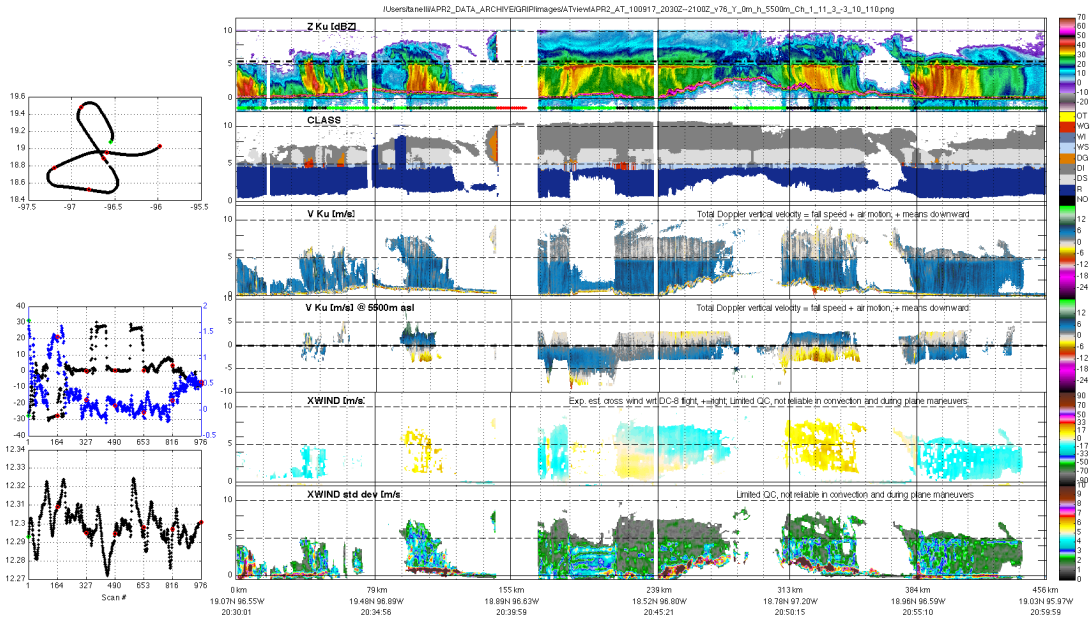
1) Vertical curtain of measured Ku-band reflectivity [dBZ].
2) Horizontal section at 3 km asl of measured Ku-band reflectivity [dBZ].
3) Horizontal section at 3 km asl of measured Ka-band reflectivity [dBZ].
4) Vertical curtain of measured Ka-band reflectivity [dBZ].



Top to bottom:

1) Vertical curtain of measured Ku-band reflectivity [dBZ].
2) Vertical curtain of measured DWR (Dual Wavelength Ratio: Ku-band reflectivity - Ka-band reflectivity) [dB].
3) Swath of Normalized Radar Cross Section difference (Ku-band – Ka-band) [dB].
4) Vertical curtain of measured Ku-band Linear Depolarization Ratio [dB].
5) Vertical curtain of measured Ku-band mean Doppler velocity [m/s] corrected for platform motion and aliasing.

Browse image 4: not validated experimental products



Top to bottom:

1) Vertical curtain of measured Ku-band reflectivity [dBZ].
2) Vertical curtain of class (by predominant particle) *Not included in format 4.x and 2.x*:
   R = Rain, DS = Dry snow, DG = Dry Graupel, DM = Dry Mix Ice (undetermined ice), WS = Wet Snow (Melting Layer), WG = Wet Graupel, WM = Wet Mix Ice, OT = Other.
3) Vertical curtain of measured Ku-band mean Doppler velocity [m/s] corrected for platform motion and aliasing.
4) Horizontal section at 5.5km asl of measured Ku-band mean Doppler velocity [m/s] corrected for platform motion and aliasing.
5) Vertical curtain of horizontal wind component cross-track to the aircraft corrected for platform motion and aliasing [m/s]. Caution: the colorscale is adaptive and changes from plot to plot. *Not included in format 4.x and 2.x.*
6) Vertical curtain of the standard deviation from horizontal wind component in cross-track to the aircraft corrected for platform motion and aliasing [m/s]. This is a measure of confidence for the plot above: large values in this plot indicate less reliable cross-wind estimates. *Not included in format 4.x and 2.x.*

Contact Information

This data is intended for research rather than operational use, and users should contact the APR-2 team regarding its use, especially before publication or public presentation.
This is the first official release of APR-2 data from SEAC^{4}RS 2013: these products that are still undergoing validation and quality control. Users are invited to address questions and provide feedback to the contact below.

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Data Use Disclaimer

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